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Function of the Laboratory

—IN—

SECONDARY EDUCATION.

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—BY—

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THE FUNCTION OF THE LABORATORY IN SECONDARY EDUCATION.

BY S. E. COLEMAN.

It is a trite saying that there is nothing new under the sun, and though it has been disproved again and again during the present century by the achievements of science, yet I fear that nothing I may have to say on the subject of science will in any measure serve as a new proof of the falsity of the proverb. However that may be, what I shall present to you is largely the result of my own experience, both as a teacher and as a student of science; and whether old or new, true or false, it represents my personal convictions. These doubtless will be modified by further experience; but such as they are, I give them to you.

Concerning the scope of the subject it will be noted that it is limited to secondary education. The subject of nature study in the grades is so broad and is at the present time arousing so great an interest that it has this year been assigned to a separate round table; and anything I may have to say upon that subject will be merely incidental. Neither shall I enter upon a discussion of the several functions of laboratory work in colleges, universities and technical schools. In these the functions are many because the aims are many. In secondary schools the function is one for the aim is one—education; not a special or technical education with a leaning toward this or that "practical" something-or-other, but a symmetrical unfolding of the latent possibilities of the mind.

In considering the means by which the science courses can best contribute toward this end, it is important to recognize first of all that it matters less *what* is taught than *how* it is

taught. Any one of the sciences of the high-school course may be taught in such a way that its educational value will be insignificant, and any one of them may be taught so as to produce valuable results. I do not mean that it is immaterial what we teach, or even that it is a matter of little importance. On the contrary, I believe that the choice of material for the science course demands greater discrimination than for any of the other courses of the high-school curriculum; nevertheless scientific education does not mean a knowledge of this or that group of scientific facts so much as it does an attitude of the mind toward scientific truth in general, and a mental discipline for which no other subjects can so well be utilized. But these results can be accomplished only by right methods of study. If the choice of material for the science course is difficult it is not because we have so little but so much from which to choose; and in making this choice the chief consideration should be that the material chosen shall be that which, under the existing conditions, furnishes the best opportunity for right methods of study.

What, then, are right methods in the study of science? Since we can really know only that which we have experienced or which we can interpret through our experience, it follows that the foundation of all sound instruction in science must be a knowledge of things and of phenomena obtained through the senses, and not a second-hand knowledge about them obtained from text books or from the teacher. Perhaps you regard this as so nearly axiomatic that it is unnecessary to dwell upon it or even to state it. Yet there are some who think that the requirements of nature study in the grades are met by the use of nature readers; as if every need of the budding intellect could be met by words, words, words! In conversation a short time since with the special teacher of nature work in one of the northern cities of the state, she remarked that one of the greatest difficulties she had to contend with was that the grade teachers told their pupils the things that they should find out for themselves. She would leave an outline of work which, if properly taught, would be sufficient for a month, and on her next visit a week later, the teacher would say: "Give us something more to do; we have finished what you gave us last time."

A fine example, indeed, of the "pouring in" process; which is based upon the idea that the acquisition of the greatest number of facts in the least possible time (through the exercise of the memory) is the chief consideration; rather than the development of the child's powers of observation and expression. That teaching is best which develops in the child the greatest measure of self-reliance and the greatest power of independent effort. The value of a teacher's services is measured less by her skill in telling than by her skill in leading her pupils to find out for themselves. I believe that the education of today is characterized by an excessive zeal to make everything as easy as possible for the child, and that this zeal defeats its own purpose in that it produces minds confirmed in the habit of dependence and having little capacity for spontaneous activity.

The laboratory, when properly utilized, is a strong corrective of this tendency. I do not mean by this that its only function is that of an antidote for certain possible or actual evils of our educational methods. Its utility has a far more positive basis, which is but emphasized by contrast with such evils. In the laboratory the pupil's task is to find out something that he did not know before, and to get it by the direct interrogation of nature. The teacher guides and directs, but it is the pupil who observes, acts, and thinks. The amount of thinking done may, of course, be a very small minimum; for the work may be done in a perfunctory and mechanical way. But if the student is held responsible for an intelligent interpretation of what he sees and does, the laboratory work, more than anything else, will tend to make him resourceful and self-reliant.

The science courses should stand in close relation to the every-day experience of the child; for it is not in the laboratory alone nor even chiefly that he comes into contact with things. When he enters the high school his mind is already stored with a large and miscellaneous body of facts, each of which should ultimately find its place in that orderly and systematic whole which we call scientific knowledge. The science courses, more especially through the laboratory work, afford the means of extending and systematizing this, as yet, unorganized material.

It teaches the pupil the precise laws and principles stripped of all adventitious and confusing phenomena. This leads to definiteness and clearness of conception such as cannot be secured in any other way. The pupil turns from the experiment equipped with the knowledge by means of which he can interpret one or more of the, to him, hitherto hidden mysteries of nature. For example, the pupil, in the physical laboratory, studies capillary phenomena by means of a glass of water and a set of small glass tubes. Rightly interpreted, this enables him to understand how a lamp wick supplies the flame with oil, why blotting-paper must be porous, why a pen point is slit, and why the occasional cultivation of the soil in summer helps to preserve its moisture. The laboratory course in physics will directly or indirectly suggest the answers to such questions as: how a kite is sustained in the air; why a handkerchief cannot be thrown as far as a pebble; why a vessel without a cargo carries a ballast; why a bicycle rider must lean inward when riding in a curve; why a hot day seems hotter and a cold day colder if the atmosphere is humid than if it is dry; why a carpet seems warmer to the bare feet on a cold morning than the bare floor does; why a fall of the barometer indicates the approach of a storm; etc.

The laboratory work should be further supplemented by systematic outdoor observation. In physical geography the pupil should be encouraged to observe the points of sunrise and sunset at different seasons; the diurnal motion of the moon and stars; and the annual motion of the stars. He should determine the altitude of the sun at noon at different seasons by means of the shadow of a vertical stick (the gnomon of the ancients); also the altitude of the north star by an equally simple method. He should observe local examples of weathering and erosion; of stratification; and of tilting, folding and faulting of the strata. In botany and zoology the pupil should become familiar with the objects of his study not only in the laboratory but also in the field. He should study them in their relations to their environment; and thus by his own observations become acquainted with the salient facts of their life histories.

Thus the facts of experience already acquired, or that may be acquired during the high-school period by systematic use of the senses during out of school hours, furnish the material with which to enrich and supplement the laboratory course; while the latter serves the no less important purpose of presenting with the greatest possible simplicity the fundamental facts and principles by means of which the every-day experience is interpreted and made significant.

An important question in all science teaching is the use to be made of text and reference books. Only by observation and experiment can a sure foundation be laid; but it is neither necessary nor desirable to limit the student to these means of instruction. On the contrary he should be taught to make profitable use of scientific literature; for in so far as he does so he becomes heir to the great wealth of scientific knowledge already accumulated by the labor of others. The danger, however, is that the student will rely too much upon books rather than too little; for in his other studies he has learned to regard books as the first and principal source of information.

But the use to be made of books will be mainly determined not by the pupil for himself but by the manner in which the course is conducted; and in this regard there are at present in vogue two widely divergent methods of procedure, and an intermediate method fairly differentiated from the other two.

In one, the text book is the central and determining element of the course; the experimental part is incidental and subordinate. The study of the text, especially in physics and chemistry, is usually carried well in advance of the laboratory work; which in consequence assumes the character of confirmatory evidence of what has already been learned from the text book and from the experimental illustration accompanying the recitation. The argument for this method is admirably stated in the preface of a popular text book of physics, from which I quote the following:

"As a natural reaction from the old *regime,* in which the teacher did everything, including the thinking, came the method of original discovery; the text-book was discarded and the pupil was set to rediscovering the laws of physics. Time has shown the fallacy of such a

method, and the successful teacher, while retaining all that is good in the new method, has already discovered the necessity for a clearly formulated, well digested statement of facts, a scientific confession of faith in which the learner is to be thoroughly grounded before essaying to explore for himself.

"With no previous instruction, the young student comes to the work without any ideas touching what he is expected to see, with entire ignorance of the methods of experiment, and without skill in manipulation. He has no training in drawing conclusions from his own experiments. He is not a skilled investigator, and will be apt to discover little beyond his own ignorance, a result, it must be confessed, not entirely without value. Before the pupil is in any degree fit to investigate a subject experimentally, he must have a clearly defined idea of what he is doing, an outfit of principles and data to guide him, and a good degree of skill in conducting an investigation.

"It is not necessary that the pupil should traverse the entire subject of physics before taking up laboratory practice, but he shoud be kept in his class-work well ahead of the subjects forming the basis of his laboratory experiments."

In the opposite method the laboratory course is made the central and controlling feature of the work; the text and reference books are supplementary. The method is based upon the idea that independence and self-reliance in observing and in drawing inferences from what is observed can not be developed if the student always undertakes the laboratory work fortified with a pre-judgment of what he is to see and what he is to conclude. An admirable text-book of physics constructed upon this plan is that of Hall and Bergen. It contains a laboratory course, which is the dominant feature of the book; the theory being developed from the experiments. Colton's Practical Zoology, which is a laboratory manual only, follows this method. I quote from the introduction the following in regard to the plan of the book:

"The aim is, not to describe for the student, thus robbing him of the opportunity to develop his own powers of description, but to name the parts, telling merely enough to enable him to recognize and apply the names to them. This makes a real connection between words and things.

"It is thought best for the student to make many of the definitions for himself. A definition thought out by the student himself, imperfect though it be, is of more value to him than a perfect definition

learned from a book, which often appeals to mere memory. . . . . It develops a boy more to earn a dime than to receive a dollar as a gift.

"If the main object of this study is the mere acquisition of facts, full descriptions of most animals can be elsewhere obtained; but if the more important part in education is to lead the pupil to see and think for himself, then some such method as this should be used.

"The underlying object of all our teaching is to make seeing, thinking, self-reliant, honest men and women. All branches of natural science, rightly pursued, are powerful means to this end. . . .

"Do not set out with the intention of finishing this book in a given time; zoölogy is the study of *animals;* study animals as long as the time allows, trying to learn as much as possible from a few typical forms; this will give a better view of the animal kingdom than reading many books concerning many animals."

To summarize: By the first method the order of procedure with a topic is (1) study of the text-book, (2) recitation, frequently with experimental illustration by the teacher, (3) the laboratory work. By the second method it is (1) the laboratory work, (2) study of the text-book and references, (3) recitation and discusison, first with reference to the interpretation of the experiments, then to their application as suggested by the pupils' reading. The latter will be illustrated by experiments performed by the teacher as occasion requires, but not to the same extent as in the preceding method.

The intermediate method makes the laboratory work more nearly co-ordinate with the other part of the course. In physics, according to this plan, the order would, in general, be somewhat as follows: (1) qualitative class-room experiments by the teacher, presenting fundamental phenomena, for example, refraction and the formation of images, the corresponding part of the text being assigned for reading and discussion; (2) the laboratory work, developing mainly quantitative relations; for example, the index of refraction of glass and of water, the focal length of a lens, and the study of conjugate foci; (3) a discussion of the experiments, together with any further application of the laws developed from them.

The relative value of these three methods remains to be considered. It is to be expected that there will be considerable difference of individual opinion on this point, and to a certain

extent this is admissible; for the individuality of the teacher necessarily plays an important part in determining what is best for him. Nevertheless, if the principles I have endeavored to set forth are true, the first method must be unqualifiedly condemned. The difference between the other two is much less important; yet it seems to me the preference is decidedly in favor of the second. In answer to an objection quoted above, it may be said that this does not mean that the pupil is to be turned loose in the laboratory to rediscover the laws of physics or of any other science by the method of original discovery. The original investigator is first of all a person of rare intellectual endowments; in the second place he is guided in his researches by a knowledge of all that his predecessors have discovered in his chosen field of investigation. Since the young student rarely has the first and never the second of these qualifications, it is necessary to provide him with substitutes therefor. These are the laboratory manual and the teacher. The objection above quoted continues: "Before a pupil is in any degree fit to investigate a subject experimentally, he must have a clearly defined idea of what he is doing, an outfit of principles and data to guide him, and *a good degree of skill in conducting an investigation.*" It seems pertinent to ask how a person can acquire "a good degree of skill in conducting an investigation" before he has begun to investigate. It is very much like advising one not to go near the water until he has learned how to swim. Since the one idea is no less absurd than the other, a formal answer to the objection is unnecessary.

We have so far given attention almost exclusively to the kind of discipline the laboratory should afford and the best methods of securing it. It remains to consider very briefly the availability of the several sciences as means to this end; with reference particularly to the special function of each and the order in which they should be pursued.

As I have already said, we are not at a loss for material. In the report of the Committee of Ten of the National Educational Association the following sciences are considered available for high schools: physical geography, botany, zoölogy, physiology, chemistry, physics, astronomy, geology, and mete-

orology; affording in all enough material for a daily lesson in science for eight years without going beyond the scope of existing high-school text-books.

The subjects chosen for the high-school course from this or any other list should be those that are of the greatest value as information and as a means of mental discipline. Their disciplinary value must be judged by the principles already set forth. What shall be the test of their value as information? In the first place, I am pleased to admit that the "practical" value, in the utilitarian sense, of the information to be obtained from any one of these subjects, so far as it can be taught in the high school, is so small that it is not worth consideration. And I will add that the practical value, in this sense, of any subject is the least of all the considerations that should determine its right to a place in the school curriculum. It should be understood that I am not here speaking of technical and professional schools, whose value no one will deny, and whose advantages should be accessible to all who desire them; but of the public schools through which all must pass in order to secure a liberal education. The value of the elementary science courses as information lies in this: *they interpret to the student his material environment and its phenomena.* A person without this knowledge is like Alice in Wonderland, who sees so many inexplicable things no less wonderful than the grinning Cheshire cat, which had a habit of vanishing slowly, "beginning with the end of the tail and ending with the grin, which remained some time after the rest of it had gone," that she finally ceases to expect any reasonableness in such a mad world; and among her later adventures holds a conversation with the weeping mock-turtle, without any consciousness of the strangeness of the situation. You smile at the absurdity of such conceits, yet the literature for "grown-ups" contains absurdities no less impossible, which are narrated as plausible happenings. Probably the majority of the readers of "King Solomon's Mines" have not considered it at all remarkable that "the full bow of the crescent moon" should appear above the eastern horizon shortly after sunset, "filling the earth with a faint refulgence"; that on the following night the full moon

should rise "in splendor" at about ten o'clock; and that the next day there should be an eclipse of the sun "causing total darkness for half an hour or more."

Those subjects or topics are most valuable as information which treat of the most conspicuous or most habitual elements of our physical environment. They are also well adapted to the requirements of an introductory course in science, because they are already more or less familiar. The early work in science should be an interpretation and systematization of facts already familiar, rather than the acquisition of new facts. Such a course will most surely awaken in the child an interest in science, because it affords a ready insight into its meaning and methods. The course which most nearly fulfills these requirements, is physical geography, which is defined in the report of the Committee of Ten as the study of "the physical environment of man." Those familiar with recent text-books on this subject know the wide range of facts and phenomena which they comprehend. The things which lie nearest at hand in our every-day life are here considered, whether they belong to the sciences of physics, chemistry, botany, zoology, astronomy, geology, mineralogy, or meteorology. Valuable results will be obtained from the study and discussion of a good text-book on the subject, if supplemented by systematic outdoor observation and field work as already suggested. But some experimental illustration in the class-room is almost indispensable, and much is desirable. In addition to all this there should be a *very* elementary laboratory course to accompany the study of the text, and no school that is without it should be regarded as having reached a satisfactory standard of efficiency in this subject.

After this general introductory course, the more specialized courses properly follow. But in what order? For an answer I cannot do better than to quote from the report of the subcommittee on zoology to the Committee on College Entrance Requirements of the National Educational Association (1899). The report says:

Studies on living things appeal more strongly to students of fifteen than to those of seventeen years of age, whereas the reverse is

true of precise formal argument. The power of exact reasoning cannot be said to develop early, and the less formal methods of biological science are also transitional to those of physics and chemistry. Furthermore, the mathematical training necessary for physics particularly is not obtained by the pupil, under present programs in secondary schools, early enough to allow the introduction of work in physics before the third year of the secondary course; hence your sub-committee is all but unanimous in recommending that, since work in zoölogy does not require the rigid training necessary for more formal work in physics and chemistry, it should precede work in these branches. It should, however, be preceded, in its opinion, by a year in general science and physiography.

"Whether illustrated by the study of plants or animals, the phenomena of life are so similar and so clearly complementary that a rational arrangement of courses calls for study of botany and zoölogy in successive terms or years. Various circumstances may determine in the individual case the order to be followed, yet neither should be studied at the expense of the other, but both receive a due share of attention."

Among the biological sciences botany, zoology and physiology are all available; but since at the most there is not time for more than two, it is important to consider which are the most valuable for the purposes of secondary education. In this connection it is significant that in the report of the Committee on College Entrance Requirements physiology is not even mentioned, and also that it is not in the list of subjects preparatory to our state university. The conference on natural history in its report to the Committee of Ten, says:

"While physiology is one of the biological sciences, it should be clearly recognized that it is not, like botany, and zoölogy a science of observation and description; but rather, like physics or chemistry, a science of experiment. While the amount of experimental instruction (not involving vivi-section or experiment otherwise unsuitable) that may with propriety be given in the high school is neither small nor unimportant, the limitations to such experimental teaching, both as to kind and as to amount, are plainly indicated. For this reason the study of physiology as a component of the high-school course should be regarded as of importance rather as an informational than as a disciplinary subject, and should be taught largely with reference to its practical relations to personal and public hygiene."

These statements apply with still greater force to the teaching of physiology in the lower grades; and if the subject is

continued, as it sometimes is, through the eight years of the primary and grammar school course, with unending reiterations upon such topics as bones, joints, tobacco, nervous system, stomach, heart, alcohol and the stomach, liver, food and stimulants, opium, digestive organs, narcotics, kidneys, muscles and alcohol, tobacco, opium, bones, and so on *ad nauseam*; and if in addition to all this, a course in physiology is prescribed in the high school, the subject, in my opinion, is receiving an amount of attention out of all proportion to its relative importance, either as an informational or as a disciplinary subject. In the lower grades it is of necessity almost entirely an informational subject, taught upon authority and appealing to the memory only. For this reason, the report on physiology quoted above recommends that in these grades the subject be limited to "simple and practical instruction upon the subject of personal health and its care." "Such instruction," the report continues, "should rather be given and received (as many other things concerning conduct must be received by young children) upon authority, than as an appeal to the judgment of the pupil as based on his physiological knowledge."

With the facilities afforded by a properly equipped biological laboratory, a course in physiology in the high school may be given that will have an important disciplinary value. The laboratory work will be partly experimental, but mainly observational, consisting for the most part of dissections of the lower animals, including some microscopical study of the various tissues. But as the experimental work deals mainly with fermentation, and with the chemistry of foods and of the digestive processes, and as these subjects can not be adequately presented without a considerable knowledge of chemistry on the part of the pupil, they would better be given as a part of the course in that subject. Moreover, since the dissections and other observational work of the laboratory course in physiology are in reality studies in comparative anatomy and physiology, it would be much more valuable if amplified and given as a laboratory course in zoology. The reading and

recitations accompanying such a course may include all that the pupil needs to know of human anatomy and physiology.

It will be assumed without further argument that botany and zoology should be given a place in the high school curriculum, following a course of one or two terms in physical geography and general science. It is not my purpose to discuss the character of these courses further than to protest against the excessive use of the compound microscope. Some knowledge of vegetable and animal histology is necessary, but it is more important that the pupil should be trained in the observation and in the knowledge of things as they appear to the unaided vision than as seen through an expensive instrument, which few will ever possess and which none carry habitually with them. With a compound microscope before his eye the pupil is looking at the thin edge of his subject in more senses than one. In a recent conversation on this subject, a teacher of biology told me that a young graduate of one of our universities had shown her, with great pride, a set of beautiful botanical microscope slides that she had prepared in her laboratory course at college. The teacher admired them, admitting that they exhibited greater skill in such work than she herself possessed, and finally asked the young lady what she had learned from them. "Why," was the answer, "I—I really don't know." On the use of the microscope the committee on botany reports as follows to the Committee on College Entrance Requirements:

"In the judgment of your committee the compound microscope is both useful and necessary in the demonstration of many important structures that should be brought to the attention of secondary-school students, but its excessive use in the first contact with plants is to be deplored. The compound microscope is a difficult piece of apparatus for a young student to use intelligently, a proper interpretation of that which is seen demanding considerable training, involving more total time and longer periods than are given in secondary schools. Another danger of such a course is that the contact with plants is one of structure rather than of function, and details of minute structure are not related to previous or subsequent experience, except in the case of very few secondary-school pupils; besides, it involves a needlessly extensive and difficult terminology at the first contact."

The committee on zoology, in its report to the same body, expresses a similar opinion.

As already stated, the biological sciences are largely observational and descriptive, and hence are well adapted to the early part of the high school course. On the other hand, the physical sciences, more especially physics and chemistry, treat more of phenomena than of things, and are mainly experimental. They therefore appeal more to the reasoning faculties, and are best adapted to the later years of the course. The logical aspect of the work is, however, pre-eminently characteristic of physics. The predominant questions in biology are What? and How? In physics it is Why? Elementary chemistry occupies a middle position in this respect. Like the biological sciences, it is largely concerned with the observation and description of facts; while the inferences drawn are for the most part simple and immediate, the reasoning involved being of a very elementary character. Elementary chemistry can be little else than the empirical study of the chemical properties of the common elements and their familiar compounds. The laws and theories of chemistry can be utilized only to a limited extent in giving the elementary presentation of the subject a rational basis. Elementary physics, on the contrary, consists almost entirely in the experimental study of the simpler physical laws and principles, and their application in explaining familiar phenomena. It is, in short, a practical course in inductive and deductive logic.

It follows from the foregoing that physics is a much more exacting study than chemistry, and requires for its successful prosecution a greater maturity of intellect. Hence the proper order for these subjects is chemistry before physics. There is another important reason for this order in schools where the same amount of time is devoted to each; namely, the fact that physics is the broader subject, treating of a much greater variety of things and phenomena that form an important part of man's physical environment. It therefore comprehends a much greater amount of available material, and should be given either more time than chemistry or the advantage of

the increased capacity for work that would result from the prior study of chemistry. The superior claim of physics is commonly recognized in the schools of the Eastern States. In Cambridge, Mass., for example, a laboratory course of twenty experiments in mechanics and light is given in the ninth year; in addition to which, in the English High School, physics is taken daily during the eleventh year and chemistry only three times per week during the twelfth year; while in the Latin High School physics is taken daily during the twelfth year and every other day during the thirteenth year, and chemistry is not taken at all.

Wishing to know how the students viewed these questions, I recently submitted the following list of questions, without comment, to pupils in the Los Angeles High School, who have had physics and who are now taking the second term of chemistry.

1. Do you regard chemistry or physics the more difficult? Give reasons.

2. Which subject presents the greater experimental difficulties? Is there much difference in this respect?

3. How do the subjects compare in the task they impose upon the memory?

4. How do they compare in the task they impose upon the reason and understanding?

5. Which subject do you think should be taken first? Why?

I received answers from thirty-two students as follows:

	Physics.	Chemistry.	No difference.
1. More difficult	16	13	3
2. Greater experimental difficulties..	16	3	13
3. Greater task for the memory....	4	27	1
4. Greater task for the reason......	28	1	3
5. Which should be studied first....	11	16	5

An analysis of the answers to the first and fifth questions gave the following results:

	No. of answers.
Physics is more difficult because:	
It requires more reasoning...........	11
There are many laws and principles...	3
It requires more memorizing.........	1
It is less interesting.................	1
Total	16
Physics is easier because:	
"You can reason things out better"....	3
Chemistry is more difficult because:	
There is more memory work.........	6
The experimental work is more difficult.....	1
It covers more ground...............	1
It is more abstract..................	1
(No reason given)..................	1
Total	10
Physics should come first because:	
It "lays the foundation of science," "teaches the fundamental ideas of science," etc.	3
It develops the power of reasoning....	2
There is more time for the harder study in the third year................	2
It is an aid in the study of chemistry..	2
It requires more independent work....	1
It is more interesting...............	1
It is easier........................	1
Total	12

Chemistry should come first because:

It is an aid in the study of physics.....	6
Memorizing is easier than reasoning...	4
It would prepare for the more difficult reasoning in physics.............	2
It is easier.........................	3
It teaches the distinction between chemical and physical properties.......	1
(No reason given)..................	1
Total	17

These answers are in striking agreement with what has already been said on the subject, and as that discussion was written before the questions were presented to the pupils, the answers are to be regarded as confirmatory evidence. Two of the answers to the fifth question are very aptly stated. "I think," says one, "that chemistry should be taken first because your reasoning power increases more in the extra year than your memory would. Therefore by taking physics last you have the advantage of the extra year in reasoning power." Another says, "I think that chemistry should be taken first. It is more of a tax on the memory, and by developing the reasoning power to some extent, prepares the way for more careful reasoning in physics later. Memory is better developed than reasoning power in most of us."

Concerning the subject-matter of the course in chemistry, it will be remembered that in discussing physiology I spoke of the advantage of making the study of fermentation and the chemistry of foods and of the digestive processes a part of the chemistry course. Such work as this cannot be satisfactorily done earlier, and it is much more important than any attempt at a systematic treatment of qualitative analysis. The latter can not in an elementary course be made to yield either valuable information or discipline, while the topics suggested afford both. The testing of substances, including ores and minerals,—and there should be a considerable amount of such

work,—should not be with the aid of analytical tables, which encourage mechanical work; but by outlines suggesting suitable dry- and wet-way experiments which will compel the pupil to think, and will afford an interesting and useful review of the properties of the substances tested.

On the subject of physics little need be added here. One point, however, I wish to emphasize, and it is of sufficient importance to stand thus alone. It is that the quantitative laboratory experiment must be regarded not as a proof of the law, but as a proof of the pupil. The pupil should be led to realize something of the extent and accuracy of the experimental evidence in favor of the laws and principles of physics; and this can be accomplished in no better way than by teaching him to recognize the principal sources of error in his own work and to estimate their probable magnitude. He must be taught that his experiments are crude, and serve to illustrate or to suggest rather than to verify the laws of physics. In every case where possible, the pupil should compute the per cent. of error of his result by comparing it with the theoretical value; and if the discrepancy is greater than a reasonable maximum, he should be required to repeat the experiment. If this plan is followed from the first, the pupil will be rapidly trained to do thoughtful and painstaking work. I speak from experience.

There is but little time in the high school for scientific courses in addition to those already considered, and certainly no more than these should be prescribed. But in large high schools it is customary to offer certain elective studies in the senior year, and of these I think at least one should be a scientific course. Among those available are astronomy, geology, mineralogy and an advanced course in physics. The last should be largely experimental, and should not be undertaken without a much better laboratory equipment than most schools possess.

The other subjects provide abundant material for half-year courses in astronomy, astronomy and geology, or geology and mineralogy. Mineralogy must be treated experimentally if

at all. Astronomy and geology afford opportunity for much interesting and profitable observation; but they are mainly informational, subjects. And this information should be the possession of every well educated person. I venture to say there are few things that will exert a more wholesome and elevating influence upon the youthful mind than the study and contemplation of the order and harmony of the universe through all space and all time. Our joys and sorrows are things of a day; and even the momentous questions that involve the welfare of nations soon cease to engage the thoughts of men; but there is that which endures, in the contemplation of which "ancient as the hills" seems to refer to but yesterday, and space "world wide" shrinks to microscopic insignificance before the extended vision. And through it all is order and system and harmony,—a cosmos, not a chaos. Such themes will leave an impress of no mean value upon character. The disciplinary value of astronomy is by no means inconsiderable, for it furnishes many and varied applications of the laws of physics.

In conclusion: Studies are valuable as information or as a means of discipline or both in varying proportions. From the point of view of the secondary school, scientific studies are valuable as information in so far as they impart an orderly and rational view of that which is most significant in man's physical environment. They have disciplinary value in so far as they train the powers of observation, description, comparison, reason, and judgment; and this comes mainly, though not wholly, from the laboratory work. It is hardly necessary to say that this training will be of inestimable value outside the field in which it has been acquired and throughout life. In all the complexities of human affairs, whether social, business, or political, such training will help its possessor to see clearly, reason correctly, and act wisely.

Finally, in his personal and intimate contact with nature under many and varied conditions, the student will come to realize that in nature trickery, deceit, evasion, and partiality have no part; her ways are trustworthy, impartial, reason-

able; her laws immutable, and the penalty for their infringement inexorable; and granting that such things are not the best means of developing a noble character, nevertheless they can scarcely fail to foster a love of truth, honesty, temperance, and justice, without which no character can be noble.

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THE PURPOSE AND METHOD OF EXPERIMENTAL WORK IN PHYSICS.[1]

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The Laboratory Course.

Diverse and conflicting views have been entertained with respect to the proper function of the laboratory course in elementary physics. At the one extreme it has held a subordinate position as a loosely attached appendage to the text-book course; and, in the manner of appendages, it trailed humbly behind the work of the class room. At the other extreme it has been the dominant feature of the physics course, and as such has claimed much the greater part of the time allotted to the subject. It has been wholly qualitative, wholly quantitative, and partly both. It has been made the basis of inductive teaching, both good and bad; and it has flippantly undertaken to "verify" the generalizations of experts in experimental science.

The experiment of teaching experimental physics has been tried out along all possible lines; and the good and the bad, the better and the worse, have been evaluated with some approximation to accuracy. Differences of opinion still exist; but they

[1]Excerpt from "The Physics Teachers' Handbook," a forthcoming work by the writer, read before the Pacific Coast Association of Chemistry and Physics Teachers, July 29, 1911.

relate, for the most part, to questions of minor importance. The proper field of laboratory physics, its aims, and its methods, can now be discussed with some possibility of fairly representing a majority opinion.

The laboratory work should constitute an organic and integral part of the physics course, and should be pursued concurrently with the instruction of the class room throughout the subject. Its specific purpose is to enlarge the pupil's acquaintance with the facts of the subject at first hand. This purpose is shared on an equal footing with the experiments of the class room, performed by the teacher. The experimental facilities of the class room and the laboratory are different and mutually complementary. Neither can take the place of the other.

The relative amount of lecture table and laboratory experiments may vary considerably without detriment to the subject, for there is much common ground that may be covered by either or both together; but a well-balanced development of both is necessary for the best results. The exclusive allotment of qualitative experiments to the class room and of quantitative to the laboratory is an unwise and unnecessary restriction of the field of usefulness of each. As a general rule, the quantitative work belongs to the laboratory course; but roughly quantitative experiments are often valuable in the class room, as a basis for the preliminary discussion of quantitative laws; and, where occasion demands, they may be made to serve in the place of laboratory experiments. The special field of the lecture table experiment is in the qualitative study of phenomena which can be readily observed at a distance. By the use of the projection lantern this field can be extended to include phenomena which would otherwise require minute observation at close range. In such cases, however, as well as in others which cannot be thus adapted, the laboratory offers the best opportunity for effective work. In the laboratory the pupil *feels* the increasing pressure as he pushes a light body (as a beaker) further down in water; he *feels* that a copper rod becomes hot enough to burn his fingers while a glass rod remains cold when an end of each is held in a flame; he *sees* that an object at the bottom of a vessel appears to rise as water poured in. Qualitative experiments such as these, and there are many of them, yield an experience which is different in kind and in value from that gathered in observing lecture table demonstrations at a distance; and on this score they are entitled to a place in the laboratory course.

As to the general character of the laboratory work, every experiment should measure up to two requirements. It should be real physics, and it should have a definite purpose and value as a part of the course. It is a waste of valuable time to spend the first days in the laboratory on pure measurement with vernier and micrometer calipers, the diagonal scale, the spherometer, etc., with no physics in sight. It is the specific purpose of the laboratory work to teach physics; and the experimental procedure should be as simple and direct as will serve the purpose. It is an educational blunder, as well as a waste of time, to introduce the use of micrometric instruments and the Jolly balance in the work on density and specific gravity, when the pupil has had no practice in the simpler methods of measuring and weighing.

The educational value of the laboratory work depends very largely upon the mental attitude which the pupil is led to assume toward it. Above all things else it should bear the stamp of sincerity. There should be no playing at discovery; and of real discovery there is none, for does it not consist in following a blazed trail? There should be no shallow pretense of "verifying" the general laws and principles of physics. The attitude of verification stultifies the intelligence; for it ignores both the quality and the quantity of the experimental evidence upon which the generalizations of science are founded, and it attaches a wholly fictitious value to the practice work of the student. The laboratory experiment is not a proof of the law, but an aid to the right understanding of it. This distinction is fundamental. For example, in the study of Boyle's law the pupil experiments with one gas only (air), at one temperature only, and with only a moderate range of pressure. With the apparatus commonly provided, the work is well done if it is not in error by more than one or two per cent. If this is accepted as an exemplification of the law, with a fair and reasonable approximation to accuracy, it is well. If it is further understood that the law has been established by similar but much more accurate work with many gases, for a much greater range of pressures, and at different temperatures, and that the law has thus been found to be only a close approximation to the truth, and that it fails even as an approximation for any gas when near a temperature and pressure at which it liquifies, it is well. Such teaching will foster a just appreciation of what science is, and a very wholesome and serviceable respect for scientific authority. But if the pupil is led to believe that all this, or any part of it, may be

assumed on the basis of his experiment, the work is a harmful perversion of scientific education.

It is of course true that the laboratory work affords a sufficient basis for important inferences and conclusions; but these are necessarily simple, and generally narrow and partial. Intellectual integrity demands that they go no further than the experimental data will warrant.

The most important and perhaps the most difficult problem concerning the laboratory work is to make effective use of it. If it has only such connection with the work of the class room as the pupil makes on his own initiative, it will have very little value indeed. Pupils well above the average in intelligence and steadiness of purpose generally fail to grasp the full significance of an experiment until the results have been subjected to a searching analysis under the guidance of the teacher; and the less capable members of the class are hopelessly incapable of deriving reasonable benefit from the work without this assistance. Acceptable results, duly recorded in a notebook, give no assurance of successful work. It is the interpretation and assimilation of results that counts, and that only.

The means by which this result can best be secured depend largely upon the size of the class, the time allotted to the laboratory work, and the predilections of the teacher. With a class of ten or less, individual instruction in the laboratory may suffice, especially with a double laboratory period. With only a single period for the work and large classes (fifteen to twenty-five), this becomes impossible. Under such conditions the only effective plan is to make the laboratory experiment the basis of a class discussion, after all members of the class have performed it. This class discussion or recitation should fit in with the text-book lesson on the topic which the experiment illustrates. On this plan, the laboratory work precedes the formal recitation. It is an obvious advantage to bring the two as close together in time as possible; and this is the principal reason for providing several sets of apparatus for each experiment, as discussed later.

As a further means of shortening the time interval between the work of the laboratory and the class room, the school program should be arranged, if possible, so that the laboratory days may be varied at will. Thus it may be found desirable to run three days of recitation, two of laboratory work, four of recitation, one of laboratory work, two of recitation, etc., according as the laboratory experiments may chance to fit in with the work of the

class room. The loss of the movable laboratory day is one of the great disadvantages of the double laboratory period, which, as a rule, must come on fixed days of the week.

In order to make the most out of the laboratory work, it must be brought into mutually helpful relation with the study of the text-book; each must be serviceable as a means of interpreting the other. The text and the experiments are different lines of approach to the same goal, namely, an understanding of physics. The two aids to the understanding will be most effective when used together. This leads to the practical rule that at least one reading of the text-book on the topic of the experiment should precede the laboratory hour; that the text-book should be brought to the laboratory, to be used at the pupil's pleasure and upon the advice of the teacher; and that the lesson of the experiment should be borne in mind as the text is further studied in preparation for the recitation.

I am not in sympathy with the view that the pupil should come to the laboratory wholly uninformed on the subject of his experiment, in order that he may weakly imitate the methods and weakly experience the pleasures of original discovery. True, the laboratory should afford valuable training in scientific methods and habits of thought, and nothing that militates against this should be tolerated; but the use of the text-book as recommended is not open to such objection. It should be remembered that the scientific investigator, in addition to his other qualifications, is skilled in the use of books. Before undertaking original work on any problem, he consults authorities to find out what is already known about it. To save time and useless labor, he begins his own investigations where his predecessors left off. The boy of to-day who is interested in wireless telegraphy or in aviation has learned this lesson without any help from his teachers; for he is a diligent reader of scientific periodicals which give up-to-date information on his hobby. Training in the effective use of scientific literature is no less a necessary part of scientific education than is training in the methods of investigation; and the former is more likely to be of use to ninety-nine out of a hundred pupils than the latter.

The principal factors which determine the details of laboratory management are the length of the laboratory period, the size of the classes, the number of sets of apparatus available for each experiment, and the number of pupils (one or more) assigned to each set.

The one important advantage of the double laboratory period (an hour and a half) is that it affords time for the experimental work of the exercise and for the preparation of a complete and final report upon it. With the judicious help of the teacher at the time of the writing, the errors of the record are reduced to a minimum; and, under the rule that notebooks are not to be taken from the laboratory, the record is free from the suspicion of dishonesty which too often attaches to work done on the outside. The double laboratory period usually carries with it the disadvantage of fixed laboratory days, the objection to which has already been noted; and each class takes a larger fraction of the teacher's time. With a single laboratory period, it is practically necessary to have the record completed on the outside; since it is out of the question to limit the course of experiments to such as can be performed and written up in so short a time. The only serious objection to this plan is that it puts temptation in the way of pupils who have access to old notebooks on the same experiments. This evil may be reduced to a negligible minimum, or it may become a serious menace to the morals of the class. It all depends on the teacher's ability to manage the situation. If it is clearly understood that the pupil's promotion will be determined by the physics stored in his head rather than in his notebook, and that the notebook is only a means to an end, not an end in itself, the temptation to dishonesty will not be very serious.

The proper size of laboratory classes has been the subject of much discussion. The view entertained by many that the number should not exceed fifteen, and would better be ten or twelve, appears to me untenable. If the instruction based on the laboratory work is given only as individual instruction in the laboratory; if, in other words, the pupil's laboratory experience is not correlated *in the class room* with the work of the class room, then indeed a laboratory section of ten or twelve is the maximum for satisfactory results. But why conduct the work on such a plan? It is appallingly wasteful of the teacher's time and energy to discuss in full detail the significance of each experiment with the pupils individually, and it is practically impossible to do so even with classes of ten or twelve. Nor is it clear that such individual instruction is more necessary or desirable in connection with the laboratory experiments than it is with the experiments of the class room or with the illustrations and applications of physical principles in daily life.

It is the business of the elementary laboratory to afford opportunity for gaining a selected and directed experience under good working conditions. It is assumed that the pupil will endeavor to make something out of this experience at the time. Only by constant effort in this direction does the work of the laboratory become a means of intellectual growth. But suppose the pupil fails of full success in this endeavor, as he generally will. If he is one of twelve, he is entitled only to seven and one half minutes of the teacher's time in a double laboratory period, and to half that in a single period. His needs will surely be better served if he has the benefit of a class discussion in a class of twenty or more, even if he must wait a day or two for this assistance.

If the threshing out of results is made the business of the class room, as here advocated, and if the laboratory is fully in order for the work of the hour before the class assembles, an experienced teacher can give the necessary assistance to a class of twenty-four, or even thirty. Twenty-four is the preferable maximum; for, as numbers increase beyond this limit, the details of management become more exacting, and the unavoidable noise and movement of the class begin to distract the attention and to interfere rather seriously with the work. The difference between a class of twenty-four and one of thirty in this respect is much greater relatively than the mere difference in numbers.

The question whether pupils should work singly or in groups admits of two satisfactory answers. They should either work singly or in groups of two. Other conditions being equal, twice as many duplicate sets of apparatus must be provided for individual work as are required where pupils work in pairs. With most schools this consideration alone carries the decision in favor of the latter plan; and it has other merits. The old adage that two heads are better than one holds true in the laboratory as elsewhere; and it is also true that two pairs of hands are better than one in many experiments. This plan requires more tactful management than the other, especially with large classes, since a considerable amount of talking must be permitted, but this is not a difficult problem.

Working in groups of three or more is unsatisfactory, as a rule. No more than two can participate to advantage in the use of the apparatus. The others must perforce become spectators; and, in the natural working of the plan, this role will fall to the lot of those to whom it is most congenial but least beneficial.

The weaker members of the group will also depend upon the more capable to do the thinking. But worst of all, the spirit of an indifferent member of the group is apt to prove contagious.

To secure the advantage of a minimum time interval between the work of the laboratory and the class room, several duplicate sets of apparatus must be provided for each experiment. This duplication has the further important advantage of economizing time in the laboratory, by saving the repetition of oral directions. All things considered, the best plan is to provide a sufficient number of duplicate sets to accommodate the entire class on two exercises. With pupils working in pairs, in classes of twenty-four as a maximum, this would require six sets of apparatus for each experiment. Twice this number would be necessary to accommodate all on the same experiment. The advantage to be thus gained would hardly justify the added expense.

Double the regular number of sets of apparatus should be provided for experiments where individual observation is necessary and much time would be wasted in taking turn at the work; e. g., in studying the heat conductivity of rods by the sense of touch, and in the usual experiments on point image in a plane mirror, the refraction of light through plates and prisms, the study of color, etc. It is also a practical convenience to double the regular equipment for the first few experiments of the course, in order that the whole class may start together, and take the experiments in regular order from the first day. The separation of the class into two or more groups, as may be desired, will soon take place of itself, particularly where the first exercises consist of several short experiments.

With most schools an adequate equipment is a matter of several years' growth. In such cases it is better to begin by providing two or three or even four sets of apparatus for each experiment of a minimum course than to provide only one set for perhaps a considerably larger number of experiments. As years pass, the increase in the number of experiments and in the number of sets of apparatus for each should proceed simultaneously.

The importance of system, order, and general fitness of conditions to the work of the laboratory can hardly be overestimated. In such matters the teacher should set an excellent example, and he should train his class to follow it. Boys are notoriously careless and indifferent to the litter and disorder in which they may leave their temporary quarters, whether it be at the labora-

tory table or elsewhere. The instincts and habits of the cave dweller have a strong hold upon them. As a measure of self-defense, as well as in the interests of civilization, the teacher should develop in his pupils a sense of responsibility for the condition of the apparatus and table where they are at work, and especially for the condition in which these are left at the end of the hour. The first law of a well-conducted laboratory is order.

Class Room Experiments.

The class room affords opportunities for experimental work of the greatest value to the course. Without such experiments the teaching is necessarily less effective, however fully the laboratory course may be developed. For various reasons, the experiments of the class room are, as a rule, impracticable in the laboratory; and also, as a rule, they have no laboratory equivalent.

The laboratory experiment is predetermined and fixed. It follows a set of written or printed directions, from which the pupil can rarely depart with any profitable result. The class room experiment is adaptable. Where occasion demands, it can be repeated under varying conditions until the essential facts stand out clearly; and an experiment, suggested by a class discussion, can often be improvised and tried out at once to settle a question or a doubt. Skill and resourcefulness in the adaptation of experiments to fit the questions of the class add immensely to the effectiveness of the teaching; and their exercise serves as an impressive object-lesson on the methods of investigation.

The experiments of the class room are adaptable not only in their character, but in their purpose as well. They fit into the general plan of the course in a variety of ways. Most frequently they serve to introduce new topics, particularly where the laboratory experiments on a topic are quantitative. The typical procedure in such cases is as follows: (1) Qualitative class room experiments, either preceding or following an assigned reading of the text. If the reading precedes the experiments, the teacher will expect the class to take an active part in an informal discussion of them as they are performed. If the experiments precede the reading, the teacher will comment briefly upon them as they are performed, directing the attention of the class to the significant facts to be observed, and will assign the reading of the text and the discussion of the experiments for the following day. (2) The laboratory experiments on the topic, supported by further study of the text. (3) Recitation on the

text and the laboratory experiments, together with problems and applications.

As an example, let us see how this procedure applies in studying the reflection of light. Before the pupil begins the study of mirror images in the laboratory, he should have a clear conception of beams and cones of light, both diverging and converging, of regular reflection, of angles of incidence and reflection, and of the law of reflection. These ideas are readily grasped from direct observation of beams and cones of light in a fully darkened room, into which a horizontal beam of sunlight is thrown by a porte-lumiere. Chalk dust in the air (from two erasers struck together) makes the path of the light plainly visible to the entire class. The phenomena mentioned are exhibited by reflecting the beam from plane and curved mirrors. Similar experiments can be shown with the Hartl optical disk without darkening the room. It is worth while to use both methods. Having this acquaintance with the fundamental facts of reflection, the pupil is better able to work out their consequences in the laboratory study of mirror images. Following the laboratory work, the class discussion or recitation is made the occasion for a general review and summing up of the topic.

Not infrequently the experiments of the class room are given to best advantage after the laboratory work on the same topic; e. g., experiments on applied pressure (Pascal's law) after the laboratory experiments on the gravity pressure of liquids; ways of using the lever, following the laboratory exercise on moments of force; more detailed study of the transmission, absorption, and reflection of radiant energy, following the simpler laboratory work on the same topic; and similarly in the experimental study of dispersion and color, magnetism, electromagnetic induction, etc. There is no invariable order of class room and laboratory work which is best in all cases.

The experimental illustration of many topics is best conducted wholly in the class room. In such cases the experiments will be presented from day to day, coincidently with the class discussions and recitations from the text. Among the subjects which can be presented to best advantage in this way may be mentioned the greater part of dynamics (the mechanics of accelerated motion), diffusion, vapor pressure, the greater part of sound, and the whole of electrostatics.

It is clearly a misappropriation of time and energy to have the class keep a record of the lecture-table experiments. There

is valuable training in written work, when properly supervised; but there is enough of it and to spare in connection with the laboratory experiments. To require a written account of the lecture-table experiments, in addition to the laboratory record, is to exaggerate this phase of the work beyond all reasonable proportions and to impose an intolerable burden on the class.

The equipment of apparatus for the class room should be entirely separate from that of the laboratory, and should be stored, ready for use, in an apparatus room directly behind the demonstration table. The table itself should have drawers and closet spaces of various sizes, for the convenient storing of apparatus and supplies most frequently used, such as burners, stands and supports of various sorts, glass and rubber tubing, tools, etc.

A fairly complete equipment of apparatus for the lecture table will cost from $800 to $1,000; and $500 will be necessary for a fair beginning. It is better to start both the laboratory and the class room equipment in a modest way, and to add to each from year to year, than to expend all available funds for either alone.

Provision is rarely made as it should be for the class room experiments in light. Direct sunlight is not at all necessary in the laboratory, but in the class room it is very important. One side of the class room should have a southerly exposure; and a window near the front of the room on this side should be equipped with a board shutter, through an opening in which a sunbeam can be directed horizontally into the room, from an adjustable porte-lumiere. The proper adjustment throws the beam over and along the lecture table, at a height of ten or twelve inches, where it can be used for all experiments on reflection, refraction, dispersion, and color. Sunlight is beyond comparison the best and most convenient light for the class room experiments on these topics. For most of the experiments in light the room should be perfectly dark. This requires an opaque shade for each window, in addition to the ordinary translucent shade. Both shades must be wide enough to project two or three inches into the deep grooves of a special box window-casing; and these grooves should be painted black.

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ADAPTATION OF PHYSICS TO DIFFERENT TYPES OF PUPILS.

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Need of Adaptation.

One of the chief obstacles to the best success in the teaching of physics is the heterogeneous character of the class. The fund of experience, the interests, and aptitudes, and the present and future needs of the pupil are factors which should largely determine the matter and method of the course; and these factors, as they apply to the different individuals of a typical physics class, are irreconcilably different. To compromise differences on the basis of the "average" pupil is lamentably unsatisfactory; for the average pupil, so far from being in the majority, is—like averages in general—a mathematical fiction.

Two Types of Pupils.

From the standpoint of physics as a means of education, pupils are of two principal types. With those of one type the mental habit is analytical, logical. Before they reach high school age they have developed a keen interest in the how and the why of things. They have learned to think in terms of cause and effect. Even in childhood their interest in what a mechanical toy does is quickly subordinated to the desire to find out how it works—with consequences perhaps disastrous to the toy but more or less satisfying to the inquiring mind. Thus from the earliest years through life this quality of mind manifests itself; it is native, fundamental. Pupils of this type take to mathematical work with comparative ease. They throw the burden where it belongs, not on the memory but on the understanding. They come to physics admirably fitted for the work, with a stock of miscellaneous information and experience which is extensive and very much to the point, and with interests and aptitudes keyed to the demands of the subject.

Pupils of the other type are characterized negatively by the absence or weakness of the mental attributes mentioned. On the basis of this negative characterization alone, the type includes the mentally inept or unfit. These do poorly in physics; but they are consistently poor in everything else as well. But defect of analytical and logical power is very often compensated by strength

in other directions, as shown by excellence in the languages, literature, history, art, and music. One element of strength with such minds is a retentive memory, which, on occasion, is made a substitute for reason. The inadequacy of the substitution is most evident in the mathematics and in physics, where in extreme cases it breaks down completely.

The above classification does not divide the sexes, but it does unmistakably show a sex difference. Among high school pupils a very large majority of the first type are boys. The second type includes most of the girls, together with a considerable percentage of the boys. Whether the difference of type, in so far as it is attributable to sex, is native or acquired or partly both is not germane to the present question. It is simply a fact to be reckoned with in education.

The Educational Problem.

How best to adjust the instruction in physics to the special needs of these two classes of pupils is the problem demanding solution. It is not solved by giving a course adapted only to the more capable boys, leaving it optional with other pupils to take the work and get what they can out of it or to decline it, as they may choose. Neither is it satisfactory to adapt the work to the less capable, thus depriving the strong of that which is for them most worth while.

In the small high school, where there is only one class in physics, the best that can be done is to supplement the class instruction with more or less of individual help, the twofold purpose of the individual work being to help the weak over the minimum requirements of the course, and to provide extra work for the strong according to their ability. With a very small class, conditions approximate to the ideal in this respect, for the instruction can be very largely individual.

In large high schools the problem admits of various solutions. It is solved as an incidental feature of larger educational issues where several high schools of different types are maintained in the same city. The physics course of the manual training or the technical high school will naturally differ from that of the Latin school or a school for girls. It is not the purpose of the writer to discuss the large possibilities afforded by such exceptional conditions, but rather the adaptations which may be made to advantage in the undifferentiated high school of the large majority of our American cities.

Adaptation in such schools usually takes the form of a general year course, open to all students, followed by a more advanced half year or year course, intended primarily for those who are preparing to enter college or technical school. This plan has obvious advantages, but at best is only a partially successful compromise. If the work of the first year is reduced in amount and adapted in character to the less capable members of the class, it is not of the sort that should be given to the others. For them the work is an occasion for half effort and a discipline in the art of loafing. The advanced course is a confession of maladjustment, being in the nature of a supplement to incomplete work. If given only for a half year, it necessarily consists of disconnected fragments, which are only imperfectly articulated with the work of the introductory course.

Segregation of Pupils.

The adequate adjustment provides for the segregation of the pupils from the beginning of the subject. There is much to be said in favor of separate courses in physics for boys and girls. This is not a segregation according to ability in the subject or according to mental type, but rather in conformity with the normal daily experience, interests, and future needs of the sexes. But the educational values of the subject are not so largely influenced by sex as to fully justify segregation on this basis alone. Mental type, as above outlined, should largely determine the scope and character of the work attempted and the methods of instruction. It is a waste of time to emphasize the mathematical side of physics with pupils who have neither mathematical inclination nor ability, whether they are boys or girls; but such work is of great value to boys who have mathematical ability. And further, there are boys as well as girls whose daily life has awakened but little curiosity concerning physical matters in general, and whose physical concepts are vague and chaotic. These need the same sort of help, regardless of sex; and the boys would not get this help in a class with capable fellows.

The Oakland Plan.

Giving due weight to all elements of the problem, the best solution apparently is to offer two parallel courses in physics, differing largely in method and in the amount and character of the subject-matter, but open to both sexes. This plan has been followed for some years in the Oakland High School, and it

works well. The two courses are designated respectively as full and brief physics. The full course is intended primarily for the more capable boys, and is taken by all who need physics for their work in college or technical school. With a selected class of pupils, the work is more vigorous and thorough than is ordinarily possible. The mathematical side of the work is emphasized, and includes incidental instruction, as occasion demands, in the sensible use of mathematics as a tool. Much attention is given to the practical applications of physics in daily life. The brief course dwells at greater length on the qualitative aspects of phenomena, omits much of the usual mathematics of the subject, reduces and simplifies the work in mechanics, takes fewer quantitative laboratory experiments, devotes less time to practical applications. Astronomical topics are introduced here and there, as they fit into the regular order of the work. Thus in dynamics, the motion of the earth and planets round the sun and of the moon round the earth, the bulging of the earth in equatorial regions due to rotation, the apparent diurnal motion of the starry heavens explained as the result of the earth's rotation, and the apparent seasonal motion as the result of the earth's revolution round the sun (based on observation of the brightest stars and some of the principal constellations), nature of the sun and stars as distinguished from the planets, relation of the solar system to the stellar universe. In heat, the inclination of the earth's axis, varying length of day and night, cause of the seasons, source of the sun's heat, solar energy as the cause of terrestrial phenomena (winds, rain, plant growth, etc.), physical conditions on the moon and Mars. In light, eclipses of the sun and moon, phases of the moon, the solar spectrum and its teachings.

The full course presupposes ability, aptitude, and adequate preparation for the subject. A good record in mathematics is regarded as evidence of fitness for the work. Although chemistry is not made a prerequisite, it rarely happens that any member of the class has not taken the subject. The full course thus fits in with a high school education which is somewhat specialized along mathematical and scientific lines.

The aim of the brief course is the general educational aim. It presupposes no specialization and looks forward to none. It purports to deal with matters of general interest and importance, and welcomes students whose intelligence and general training are such as may reasonably be expected of all third and fourth

year students in the high school. The only specific requirement is a certain minimum of algebra and geometry. As regards the content of the course, it is certain that all girls and many boys are more interested in learning something of the orderly plan and meaning of the universe at large than they are in learning details about hydraulic presses, steam pumps, steam engines, dynamos, etc. The brief studies in astronomy above outlined never fail to arouse the deepest interest, which reacts to the benefit of the more prosaic side of the work. It should not be overlooked that this astronomy is also applied physics, serving admirably to illustrate the laws and principles of the subject, and that, as information tending to broaden the mind and to enlarge one's outlook upon life, it is worth more than much of the practical physics that we are at present so intent upon bringing into the high school course.

Time and Credit.

The two courses are given the same amount of time on the school program, and each is completed in one year; but the full course demands more time on the outside, and ranks as a course and a half toward graduation. The work would be extended over a year and a half if circumstances permitted.[1]

Pupils in the Brief Course.

The choice of the girls is the brief course, almost without exception. It is preferred even by those who are fully competent to take the other, because the subject-matter and the less intensive treatment are more to their liking. It is taken by a considerable number of the boys for the same reason, and not infrequently for the further reason that they have neither the training nor the ability demanded by the full course.

A Suggestion.

It is not essential to the plan and purpose of the brief course that it should include the astronomy outlined above, or any part of it. Although very much worth while, there is an abundance of good material that may take its place. Elementary meteorology is simple applied physics, is of general interest, and serves admirably to illustrate many topics in mechanics

[1]Since this article was offered for publication, our school program has been arranged to give 7 periods per week during the first half year and 8 periods per week during the second half year to the full course. The time allotted to the brief course remains, as before, 5 periods per week through one year.

and heat. This material will be found fully worked out in any elementary text-book of physical geography. Of like utility are such topics as the heating and ventilation of buildings, the fireless cooker, the use and dangers of volatile, inflammable liquids (gasoline, kerosene, alcohol), including tests of flashing point and burning point, artificial illumination, electricity in the home, etc.

A RATIONAL SOLUTION OF DISPUTED QUESTIONS.

The differentiation of elementary physics into two parallel courses affords the only rational solution of certain questions on which there has long been an irreconcilable difference of opinion among physics teachers. Should the quantitative side of physics be brought out strongly, with quantitative experiments, derivation of formulas, solution of numerical problems, etc.? Yes, in the full course; in the brief, no.

If any class of students can derive reasonable benefit from the present mathematical courses of the high school, then the same class of students can derive equal or greater benefit from the mathematical work of the physics course. If it is profitable to study pure mathematics, it is no less profitable to put a modicum of the knowledge gained to the test of practical use; and physics offers almost the only opportunity in the high school for such use. The objection that mathematical physics is too hard is met by the answer that it is not so hard as much of the pure mathematics that the student has already taken—or endured. The objection that it is uninteresting is met by the same answer, with the advantage again in favor of physics, for the problems of physics have a more significant content. It should be admitted, however, that the argument is valid against both the mathematical physics and the traditional courses in algebra and geometry, *for a large percentage of high school pupils.* The physics teacher, when charged with inhumanity, should not attempt to justify himself by replying, *Tu quoque.* He should give the mathematical work in good measure to those who can profit by it, with full assurance that it is worth while, and should reduce it to a harmless and, let us hope, profitable minimum for the others.

The question as to the proper treatment of kinetics (the behavior of matter undergoing acceleration) finds a similar answer. With a selected class of boys, it should be possible and profitable to treat the subject quantitatively, in terms of both the gravitational and the absolute units of force; but with girls

generally and with many boys there is little profit in elaborating the quantitative relations. The choice of suitable illustrative material (practical applications, etc.) also becomes a comparatively simple matter, as already noted.

Discriminating Use of the Text-Book.

In the light of the foregoing discussion, it is clear that the use of the text-book calls for discrimination on the part of the teacher. It is the teacher's privilege to select and reject according to his own best judgment. If the contents of the text are well ordered, so that essentials can be taken and non-essentials omitted without break in the general plan and continuity of the subject, then an overplus of material becomes a valuable feature of the book; for it affords opportunity for choice, and its presence invites attention and stimulates interest.